Fractured and weathered basement rocks are important oil and gas reservoirs in various basins worldwide. This author has followed this subject very closely for over thirty years and hereby shares his knowledge and experience. This paper focuses on important oil and gas fields in Indonesia, Viet Nam, China, and Venezuela and explains how these fields were eventually discovered despite their complicated geology. Also reviewed is how the operators of these fields are able to efficiently and economically produce oil and gas from the basement reservoirs. Best practices include the following: production wells should be drilled near-perpendicular to the dominant fracture system. Exploration wells should also be drilled highly deviated rather than vertical in order to optimally intersect the dominant fracture systems. Highly focused 3D seismic such as CBM (Controlled Beam Migration) is needed to define the fracture systems in basement. Extensive core coverage is necessary to provide critically important information on the lithologies and reservoir parameters. Some of the cores should also be radiometrically age dated in order for the geologists and reservoir engineers to understand the complexities of the basement reservoirs they are dealing with. Development wells must be sufficiently deep to fully drain the reservoir. Wells should not just “tag” into the top of basement. For example wells in the La Paz Field, Venezuela which produces from granitic basement were typically drilled 500 meters into the basement. Similarly exploration wells should penetrate at least 100 meters into basement rather than just barely penetrate the top of the basement. In a general sense, fractured granites and quartzites are the optimum reservoirs. Weathered “rotten” granites can also be excellent reservoirs as can be observed in outcrop in tropical areas. Rocks such as schists and gneisses are less attractive since they are ductile and tend to “smear” and not fracture when subjected to tectonic stress. The high mafic content of schists also negates the creation of secondary porosity by weathering. Likewise, granites and quartzites are more likely to provide attractive, highly porous “granite wash” sands whereas eroded schists to not produce such good reservoirs.
Global Accumulations of Oil & Gas in Fractured and Weathered Basement: Best Practices for Exploration & Production

Requirements for Oil or Gas in Basement
- **Reservoir** – need fractured or weathered basement
- **Source** – need hydrocarbon source rocks below, adjacent or above the basement reservoir
- **Closure** – need structural closure
- **Cap** – need cap rocks above the basement reservoir

Preference Scale for Reservoir Rocks for Oil & Gas in Basement — Need Brittle Rocks
- Fractured quartzites — Most preferred
- Fractured granites
- Fractured carbonates
- Weathered granites
- Fractured gneisses
- Weathered gneisses
- Fractured schists
- Weathered schists — Least preferred

Potential of Gneisses & Schists as Basement Reservoirs
- **Gneisses**: foliated metamorphic rocks corresponding in composition to granite or feldspathic plutonic rocks
  - **Problem**: can be massive or dense or slabby with open fractures parallel to the direction of foliation; fracturing is too planar
- **Schist**: a foliated metamorphic rock with closely foliated structure consisting of parallel planes
  - **Problem**: are generally too micaceous, thinly bedded, fissile and ductile to be prone to mega-scale fracturing

Fractured Precambrian granite — vertical fractures, interior of Angola

Fractured Precambrian granite — Left Half of Outcrop is an Example of a Fracture Corridor, Interior of Angola

Fractured Precambrian granite — Detail of the Fracture Corridor, Interior of Angola

Fractured Gneisses — Eastern Margin of Kwanza Basin, Central Angola

Sketch Diagram of an Untested Basement High, an Example from Angola

Global Accumulations of Oil & Gas in Basement Reservoirs
- **ASIA**: Viet Nam - Bach Ho oil field, CNV oil field, China "burned hill" oil fields, Indonesia - Suban gas field, Tanjung oil field, Beru NE oil pool
- **EUROPE**: UK - Lancaster oil field, North Sea, Norway - Luno
- **MIDDLE EAST**: Yemen, Libya, Egypt - Gulf of Suez
- **AFRICA**: Libya, Algeria, Angola - onshore Cabinda
- **NORTH AMERICA**: Kansas, Texas, California
- **SOUTH AMERICA**: Venezuela - La Paz oil field, Brazil - onshore Carmopolis oil field

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Global Accumulations of Oil & Gas in Basement

Oil & Gas in Basement
- Quotation from the classic paper on oil & gas in basement reservoirs by K.K. Landes et al (1960 AAPG) Petroleum Resources in Basement Rocks: "Commercial oil deposits in basement rocks are not geological 'accidents' but are oil accumulations which obey all the rules of oil sourcing, migration and entrapment, therefore in areas of not too deep basement, oil deposits within basement should be explored with the same professional skill and zeal as accumulations in the overlying sediments".

Fracture Corridor

Fractured and Weathered Basement:

- Brittle Rocks
- Reservoirs
- Source(s)
- Potential for accumulations
- Sourcing, migration and entrapment
- Commercial oil deposits in basement rocks
- Exploration and production best practices
- Fracture corridors

Fractured Precambrian granite
- Interior of Angola
- Outcrop examples
- Basement rocks
- Structural and geologic importance

Fractured gneisses
- Eastern Margin of Kwanza Basin
- Basement examples
- Exploration and production relevance

Weathered schists
- Basement rocks
- Exploration and production relevance
Chinese "Buried Hill" Oil Fields

- Dangshenpu buried hill oil field found in 1983
- Discovery well tested at 1,570 BOPD and 0.5 MMCFG/D
- Reservoir rock are PreCambrian in age and are mainly migmatite granite, granulite, diabase, hornblende
- Rocks had no primary porosity but have secondary weathering and fracture porosity
- Oil column is 400 meters thick
- Estimated reserves of 190 MMbls oil

Bach Ho Fractured Precambrian Basement Oil Field, Viet Nam

- Giant oil field with reported estimated recoverable oil of 1.0 – 1.4 billion barrels
- Discovered by Mobil in 1975, oil found was in Oligocene sediments
- 1988 Vietsocpetro found oil in fractured granite basement
- Oil production peaked at 280,000 BOPD in 2005
- 2009 production down to 125,000 BOPD and declining 20,000 BOPD between 2009 & 2014
- Oil is 90% from basement and 10% from Oligocene sediments

Bach Ho Oil Field: Lessons Learned for Exploration in Asia & Elsewhere

- Most fractures inside basement are high dip angles (40-75 degrees)
- Matrix porosity in the granite is negligible
- Oil stored in macrofractures, microfractures and vuggy pores in fractures
- Porosity in fractures is only 2 – 3% but permeabilities are good to excellent at ten to thousands millidarcies MD
- Flow rates of up to 14,000 BOPD
- Giant reserves due to up to 1,500 meters of oil column

CNV Basement Oil Field in Viet Nam – Success by SOCO – Well CNV-3X Tested at 13,040 BOEPD from Fractured Granite

CNV Basement Oil Field, Viet Nam, Seismic Line Over Basement Structures

Viet Nam – Outcrop of Fractured Basement

Chinese "Buried Hill" Basement Oil Fields – North China Basin

- Dangshenpu buried hill oil field found in 1983
- Discovery well tested at 1,570 BOPD and 0.5 MMCFG/D
- Reservoir rock are PreCambrian in age and are mainly migmatite granite, granulite, diabase, hornblende
- Rocks had no primary porosity but have secondary weathering and fracture porosity
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ANGOLA – Onshore Cabinda Basement Oil Pools

- Modified after Soco International website 2005

CNV Basement Oil Field – Longest Measured Depth Well Drilled in Viet Nam at 6,123m With Over 2,000m in Granite

Bach Ho – (White Tiger) Fractured Precambrian Basement Oil Field, Viet Nam

- Two-dimensional model of the play concept for the Cuu Long basin.
Global Accumulations of Oil & Gas in Fractured and Weathered Basement: Best Practices for Exploration & Production

- **Hurricane Exploration PLC – Lancaster**
  - Basement Oil Discovery – West of Shetlands, UK North Sea
  - Sites: Lancaster, Devonian, U.K. North Sea
  - **www.gaffney-cline.com**

- **Suban Gas Field, South Sumatra**
  - Gas Reserves of Approx 7 TCF
  - Indonesia

- **La Paz Oil Field, Venezuela**
  - **www.gaffney-cline.com**

- **El Segundo Basement Schist Oil Field, Southern California**
  - **www.gaffney-cline.com**

- **Tanjung Oil Field, Kalimantan, Indonesia**
  - **www.gaffney-cline.com**

- **Kansas, USA – Precambrian Fractured Quartzite Buried Hill Basement Oil Pools**

- **Locations of Tanjung Oil Field, Kalimantan, Beruk NE Oil Pool, Sumatra & Suban – Sei Teras Gas Field, Sumatra**

- **Map Showing the Main Californian Gas and Oil Fields of El Segundo, Santa Maria, Wilmington, Playa del Ray and Edison**

- **Suban Gas Field, South Sumatra 7 TCFG in Fractured Granite & Quartzite**

- **Suban Gas Field, South Sumatra Gas**
  - **www.gaffney-cline.com**

- **Best Practices - Lessons Learned!!**
  - Look for “profound” basement structures like Bach Ho (Viet Nam), Tanjung (Indonesia), La Paz (Venezuela), Lancaster (UK North Sea).
  - Look for oil in basement beneath existing oil and gas fields – “the best place to find oil is where oil has been already found”.
  - Look for optimum basement rock types like granites or quartzites
  - Drill 200 meters into basement, don’t just “tag” into it. Also drill perpendicular to the fractures, don’t drill parallel to the fractures.